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RESEARCH MEMORANDUM

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TIME VARIATION OF THE DISTANCE SEPARATING BOMB AND

DIVE BOMBER SUBSEQUENT TO BOMB RELEASE

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

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SUMMARY

A study has been made of the variation of the distance separating bomb and aircraft with time after release as applied to dive-bombing operations. Separation distances determined from this study are presented in terms of two variables only, dive angle and maximum airplane accelerometer reading; the values of separation distance include the effects of delay in initiation of the pull-out and lag in attainment of the maximum normal acceleration.

INTRODUCTION

A study has been made of the relative flight paths of bomb and aircraft in dive bombing operations. The results provide values of separation distance which account for the conditions that the pull-out is initiated some time after the bomb is released and that the maximum acceleration of the airplane is not attained instantaneously on initiation of the pull-out. The results of the calculations including these factors are presented herein as a single chart from which the separation distance may be determined as a function of the dive angle and the maximum normal acceleration attained in the pull-out.

METHOD OF ANALYSIS

The basic assumptions used in the present analysis are:

(1) The pull-out is a vertical plane maneuver.

(2) The relative acceleration between airplane and bomb parallel to the original dive path can be neglected.

(3) For the magnitudes of separation of interest the angular deviation of airplane and bomb paths from the original path is only moderate (say less than 30°). With this assumption the acceleration between airplane and bomb perpendicular to the original path may be approximated with sufficient accuracy by the accelerometer reading in the airplane.

The general approach and assumptions are felt to be as realistic as possible in the absence of a knowledge of the ballistic characteristics of the bomb. Some implications of these assumptions will be discussed subsequently. The effect of the earth's gravitational field on the path of the airplane does not have to be considered in the computations of separation distance because gravitational accelerations are the same for both airplane and bomb.

On the basis of the preceding considerations the separation distance for reasonably small times after bomb release can be calculated from a double integration (from the time the bomb is released) of the reading of a normal accelerometer located in the airplane. This integration may be expressed analytically in the general form

$$S_{t_2} = S_{t_1} + V_{t_1}(t_2 - t_1) + g \int_{t_1}^{t_2} \int_{t_1}^{t} n(t)dt \, dt \qquad (1)$$

where

S   separation distance between airplane and bomb, ft

V   relative velocity between airplane and bomb, ft/sec

g   gravitational acceleration, 32.2 ft/sec^2

$n(t)$ accelerometer reading, g units

t   time, sec

The subscripts indicate particular times at which the quantities are determined. The relative velocity at any given time can be determined by the general expression:

$$V_{t_2} = V_{t_1} + g \int_{t_1}^{t_2} n(t)dt \qquad (2)$$

Since the separation distance and relative velocity between air-plane and bomb are zero at release, the separation at the time the pull-out is initiated as given by equation (1) is:

$$S_{t_d} = g \int_0^{t_d} \int_0^t \cos \gamma \ dt \ dt = g \frac{t_d^2}{2} \cos \gamma \qquad (3)$$

and

$$V_{t_d} = g \int_0^{t_d} \cos \gamma \ dt = g t_d \cos \gamma \qquad (4)$$

where

t_d time delay between bomb release and initiation of pull-out, sec

γ dive angle, deg from horizontal

A study of time histories of dive pull-outs in actual airplanes indicates that the variation of airplane normal acceleration between the initiation of the pull-out and the attainment of the maximum acceleration can be adequately approximated as sinusoidal. This type of variation is given by the expression:

$$n(t) = \frac{n_m + \cos \gamma}{2} - \left(\frac{n_m - \cos \gamma}{2} \right) \cos \pi \left[\frac{(t - t_d)}{(t_m - t_d)} \right] \qquad (5)$$

where

n_m maximum accelerometer reading attained in pull-out in g units

t_m time at which maximum acceleration is initially attained

This assumed variation of $n(t)$ with time is presented in figure 1.

Substituting equations (3), (4), and (5) in equation (1) and per-forming the indicated integrations gives the following expression for separation distance for the interval $t_d \lesssim t \lesssim t_m$:

$$S = g\left\{ \frac{t_d^2}{2} \cos \gamma + (t - t_d)t_d \cos \gamma + \frac{n_m + \cos \gamma}{4}(t - t_d)^2 - \right.$$

$$\left. \left(\frac{n_m - \cos \gamma}{2}\right)\left(\frac{t_m - t_d}{\pi}\right)^2 \left[1 - \cos \pi\left(\frac{t - t_d}{t_m - t_d}\right)\right] \right\} \qquad (6)$$

Adding and subtracting $(t - t_d)^2 \dfrac{\cos \gamma}{2}$ from equation (6) and rearranging enables the separation distance to be expressed in the following simpler form:

$$S = g\left[An_m + \left(\frac{t^2}{2} - A\right)\cos \gamma \right] \qquad (7)$$

where

$$A = \left(\frac{t - t_d}{2}\right)^2 - \frac{1}{2}\left(\frac{t_m - t_d}{\pi}\right)^2\left[1 - \cos \pi\left(\frac{t - t_d}{t_m - t_d}\right)\right]$$

The term An_m gives the separation distance in a vertical dive. The second term is in a similar form and gives the effect of dive angle.

At the time the maximum normal acceleration is initially attained the separation distance becomes:

$$S_{t_m} = g\left[A_{t_m}n_m + \left(\frac{t_m^2}{2} - A_{t_m}\right)\cos \gamma \right] \qquad (8)$$

where

$$A_{t_m} = (t_m - t_d)^2\left[\frac{\pi^2 - 4}{(2\pi)^2}\right]$$

The relative velocity between airplane and bomb at t_m may be determined by substituting equations (4) and (5) in equation (2), which gives:

$$V_{t_m} = g\left[\frac{n_m}{2}\left(t_m - t_d\right) + \left(t_m + t_d\right)\frac{\cos\gamma}{2}\right] \tag{9}$$

If equation (5) is applied for $t > t_m$, the normal acceleration will decrease because of nature of the cosine type variation assumed. This variation is shown by the curve labeled A in figure 1. Since equation (7) incorporates equation (5), the separation distance calculated from equation (7) will reflect this acceleration variation. If the maximum acceleration is assumed to be maintained for $t > t_m$ (curve B in fig. 1), the expression for separation distance for $t > t_m$ can be determined by substitution of equation (8), equation (9), and the value $n(t) = n_m$ in equation (1) giving the expression:

$$S = g\left[\left(At_m + B + \frac{t^2}{2}\right)n_m - \left(At_m + B\right)\cos\gamma\right] \tag{10}$$

where

$$B = \frac{1}{2}\left[t_m t_d - t(t_m + t_d)\right]$$

Data on dive pull-outs show a rather wide variation in the time interval between bomb release and attainment of the maximum normal acceleration. A previous study which was not reported suggested a value of 5 seconds as a reasonable conservative value for this time interval. The Navy Bureau of Aeronautics has concurred that this value is logical and has suggested a value for the time delay between release of the bomb and initiation of the pull-out of 1 second. These values for t_m and t_d were used to calculate separation distances as a function of n_m and $\cos\gamma$ through use of equations (3), (7), (8), and (10). The parts of the separation distance determined by n_m and by $\cos\gamma$ were evaluated separately and are defined herein as S_{n_m} and $S_{\cos\gamma}$. A point worth noting is that, although $S_{\cos\gamma}$ is not dependent on n_m, it is dependent on the type of acceleration variation assumed and also on the assumed values of t_d and t_m.

RESULTS AND DISCUSSION

The parameters S_{n_m} and $S_{\cos\gamma}$ are plotted against n_m and $\cos\gamma$, respectively, in figure 2 for various times from bomb release.

The total separation distance is given by:

$$S = S_{n_m} + S_{\cos \gamma}$$

Since the actual variation in normal acceleration which would occur beyond t_m is somewhat in question, separation distances for $t > t_m$ have been calculated and are presented in figure 2 by using both equation (7) and equation (10) which correspond to the acceleration variations given by curve A and curve B in figure 1, respectively. A comparison of results obtained from the two assumed variations in acceleration shows that up to 9 seconds from bomb release the differences in estimated separation distance are small, the maximum difference being about 10 percent. Calculations obtained by using equation (7) should be limited to times less than $(2t_m - t_d)$ because the variations in acceleration beyond this time would be definitely illogical. In any case use of figure 2 should be limited to conditions where the separation distance is less than about 20 percent of the distance covered along the path after bomb release because under some conditions a separation distance greater than this percentage would result in exceeding the 30° limitation on the angular deviation of the airplane from its original path. This limitation is necessary because of the assumptions made in the analysis. The distance traversed along the path is given with sufficient accuracy by:

$$S_p = V_r t$$

where

S_p distance airplane travels along its path after bomb release, ft

V_r airspeed at release of bomb, ft/sec

As mentioned previously the present calculations neglect the separation resulting from any relative acceleration which may occur parallel to the original path of the airplane. For high ratios of bomb drag to weight and/or low dive angles, the bomb will have rearward acceleration with respect to the airplane; while for low ratios of bomb drag to weight and/or high dive angles, the bomb will have forward acceleration with respect to the airplane. In order to investigate the effect of these accelerations, separation distances were calculated for the case of an airplane in a 60° dive at a speed of 300 knots releasing a bomb for which the drag was negligible compared to its weight. These separation distances are compared in figure 3 with those obtained by the method used herein. For the case of the bomb having no drag the separation distance at 1 second from release is 8 feet greater than that

obtained for the case where no relative acceleration between airplane
and bomb is assumed and is 145 feet greater at 5 seconds from release.
The actual separation distance will depend on the bomb drag but will
usually lie in between the two curves shown in figure 3. The present
method of calculating the separation distance appears adequate in
absence of knowledge of the bomb drag because it will always estimate
a separation distance which closely approximates the smallest that can
be encountered regardless of the drag.

CONCLUSIONS

The time variation of separation distance between a bomb and a
dive bomber after bomb release have been calculated. The calculations
include the effects of delay in initiation of the pull-out and lag in
attainment of the maximum airplane acceleration. The following con-
clusions pertain to the results of this analysis:

1. The separation may be adequately defined in terms of two
variables only, the maximum acceleration experienced by the airplane
in the pull-out and the dive angle provided the time delay in initia-
tion of the pull-out and the time to attain maximum acceleration are
specified.

2. The results obtained herein should be limited to use where the
separation distance is less than about 20 percent of the distance the
airplane covers along its path after bomb release.

3. For the times from bomb release of interest the variation in
normal acceleration after the maximum value has been attained does
not greatly affect the separation distance.

4. The present method of analysis will estimate a separation
distance which closely approximates the smallest that can be encountered
regardless of the bomb drag.

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Approved: Melvin N. Gough
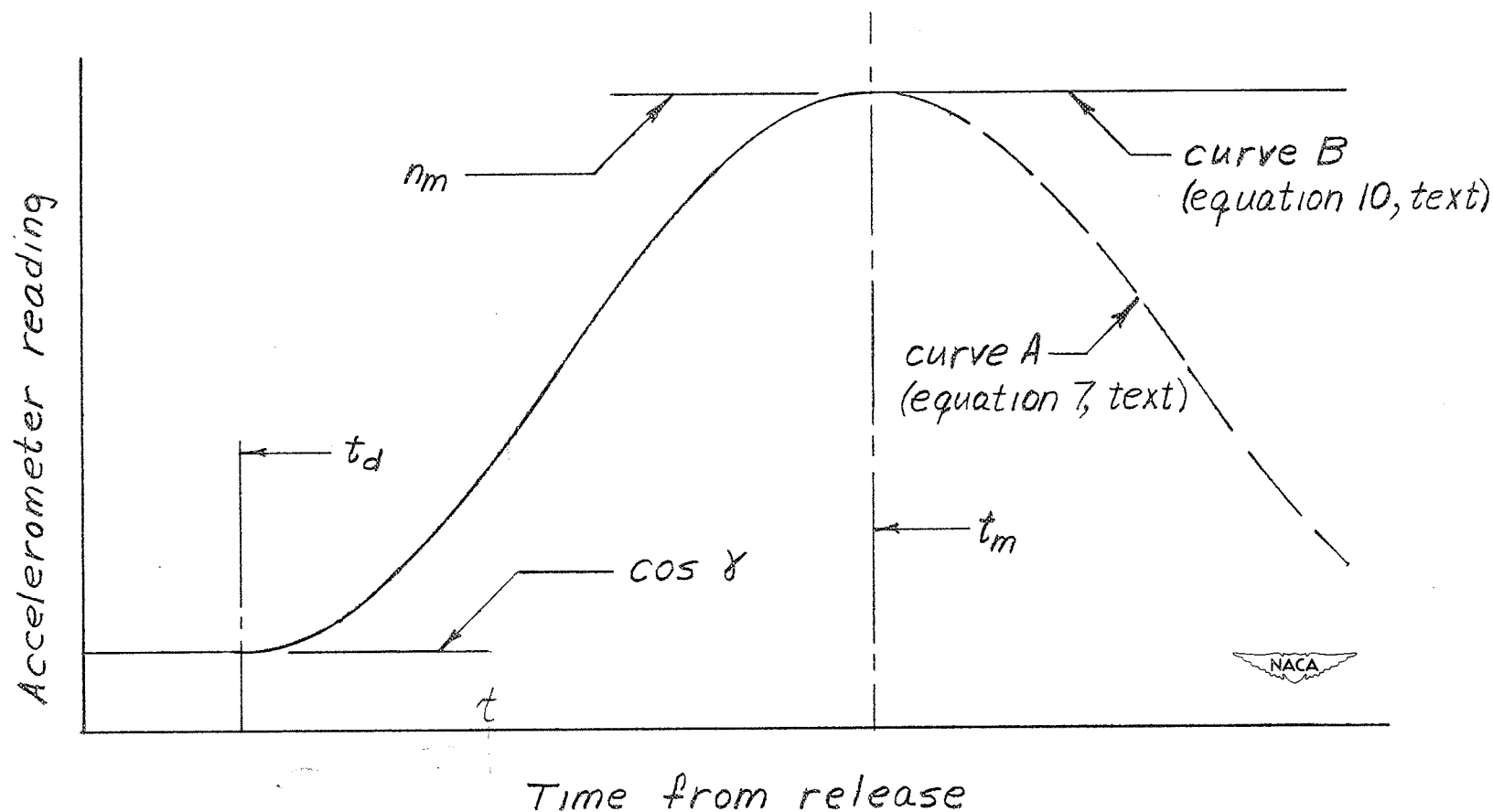Chief of Flight Research Division

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Figure 1.- Assumed variation of normal acceleration with time from
bomb release.
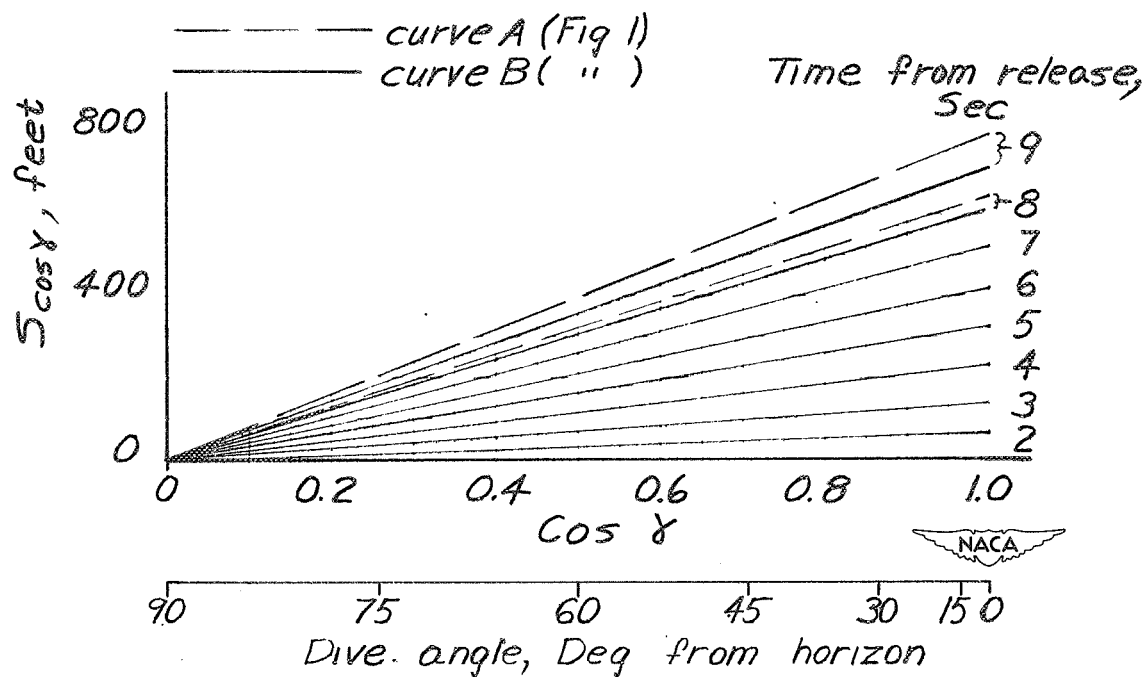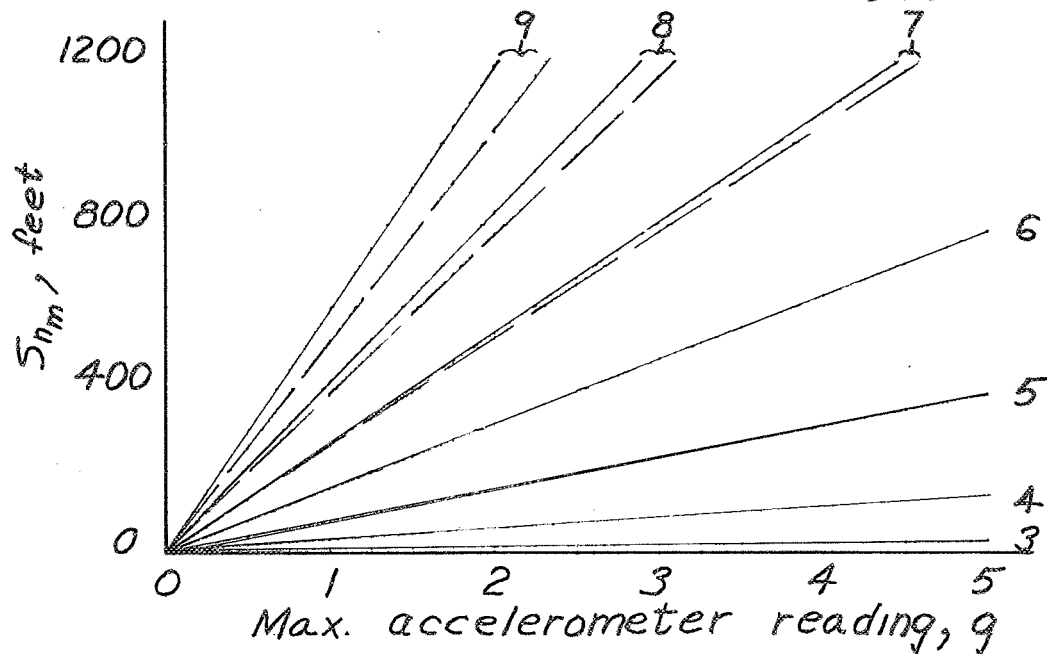
Separation distance $= S_{n_m} + S_{\cos \gamma}$

Figure 2.- Variation of separation distance with maximum normal acceleration and cosine of the dive angle for various times from release. $t_d = 1$ second; $t_m = 5$ seconds.
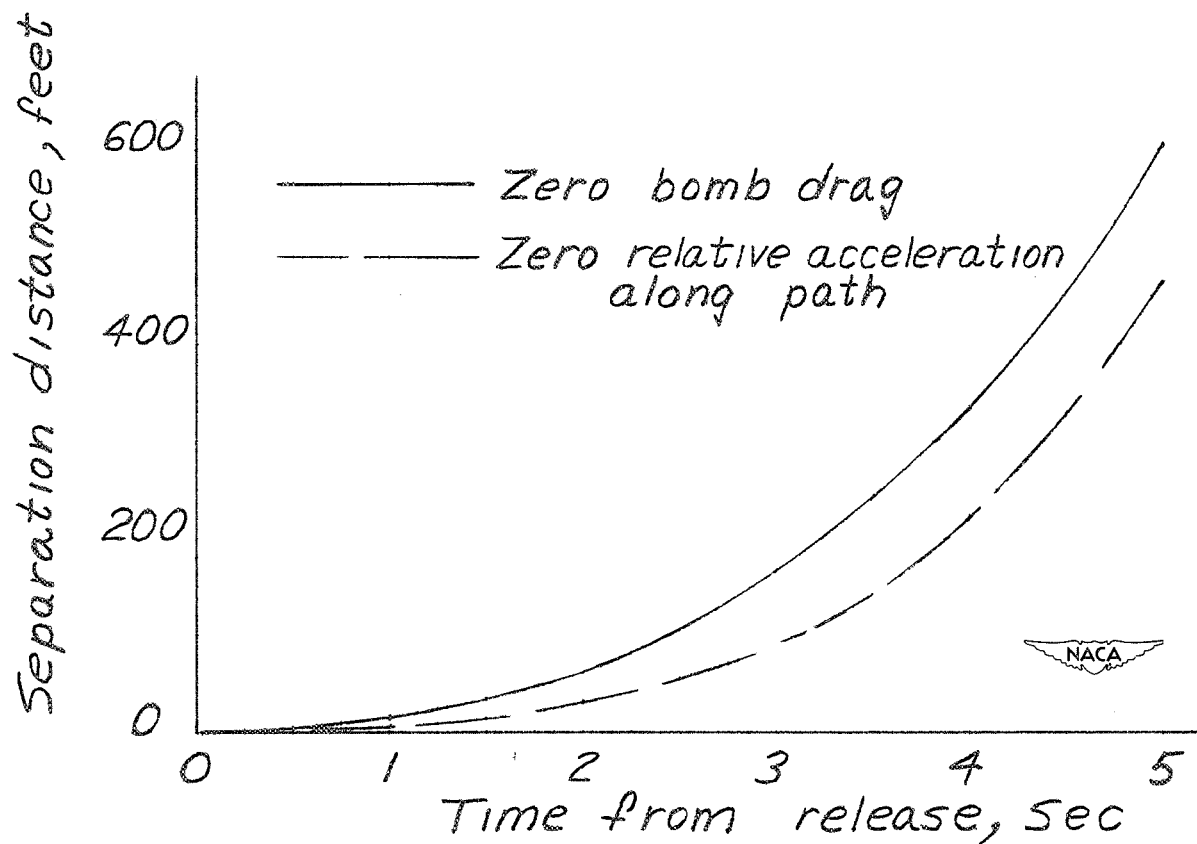
Figure 3.- Comparison of the variation of separation distance with time
for the case of zero relative acceleration between airplane and bomb
parallel to the dive path (assumed herein) with that for the case of
zero bomb drag. $\gamma = 60°$; $n_m = 4g$; $V = 300$ knots.

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ABSTRACT

Contains analysis and calculations of the separation distances between bomb and dive bomber following bomb release. Separation distances as determined by the dive angle and the maximum airplane accelerometer reading are presented in a single chart.